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Whiteness constancy: Inference or insensitivity?*

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Two general viewpoints were advanced as explanations of whiteness constancy: (a) an inferential process, in which noise illuminance variation) is suppressed, and (b) an insensitivity hypothesis, in which Os show an insensitivity to illuminance variation in well-articulated fields. Category judgments of illuminance and albedo variation were given by three Os to either unpatterned (isolated surface) or patterned (two surfaces, one of which was constant in albedo) stimuli. Judgments of the patterned stimuli differed from judgments of the unpatterned stimuli in that Os showed increased sensitivity to real albedo variation (whiteness constancy) and a corresponding decreased sensitivity to real illuminance variation, allowing the interpretation that stimulus conditions producing whiteness constancy are also those producing insensitivity to illuminance variation.

The perceptual constancies, central to many theories of perception, have been defined by a logical analysis of the relationship between distal and proximal stimuli. Our sense organs contact only proximal stimuli. Information contained in these stimuli about object properties (size, albedo, color, etc.) is perturbed by noise (distance, amount and color of illumination, etc.). The possibility exists, then, for demonstrating constancy of perception when an object property is not in perfect correspondence with the proximal stimulus because some type of noise interferes. Methodologically, constancy is measured by determining the amount of perceptual invariance of some object property when noise varies. For example, the constant appearance of the albedo of a surface with changes in illumination (whiteness constancy) can be shown by the following null-match operation. The O views a standard stimulus (gray disk) of 30% albedo under a particular level of illumination. A series of choice disks are illuminated by a different amount of light. Whiteness constancy is shown when the O picks a disk of 30% albedo from among these choice disks.

Hake (1970) has argued that this methodology and associated logical analysis are insufficient to define a series of phenomena that should be included under the title "perceptual constancies." The definition is incomplete and should be combined with other operations to produce a more general definition of constancy. In particular, Hake suggests that the criteria for demonstrating constancy should include the ability of the O to separate perceptually stimulus dimensions that are physically separate. Thus, whiteness constancy is demonstrated when the O is able to make two kinds of judgments. First, he must be able to relate judgments of surface albedo to real changes in albedo when illumination also varies. Second, he must be able to relate judgments of the illumination incident on a surface to real changes in illumination when the albedo of the surface also varies.

This definition emphasizes the noise-suppressive characteristics of constancy performance. The possibility for demonstrating perceptual constancy occurs not only when there exists noise that perturbs the relationship between some object property and the proximal stimulus. In addition, Os must be capable of responding to the noise when it varies, i.e., they must be sensitive to that form of stimulus variation. Only under these conditions can constancy be viewed as an *achievement* of the organism in which noise is suppressed. Theories of how perceptual constancy is achieved have generally suggested a noise-suppressive process, and thus follow the above definition. For example, an inferential theorist would suggest that perceptual constancy is produced when the O adjusts his experience of some object property according to the perceived amount of noise. According to this notion, whiteness constancy is achieved in the following manner. The O perceives the luminance of an object as well as the amount of light incident on the total field (illuminance). The former is adjusted as a function of the latter to result in perceived albedo (Woodworth & Schlosberg, 1954, pp. 430-433). This is known as the invariance hypothesis (Hochberg, 1964) in that there is an invariant relationship between the perceived luminance, illuminance, and albedo.

Given this expanded definition of perceptual constancy, it is possible to question whether phenomena classically considered to demonstrate "constancy" can truly be regarded as indicating noise suppression. The experiments reported here are designed to answer this question specifically with regard to whiteness constancy. In particular, an attempt will be made to demonstrate that illumination does *not* serve as noise perturbing the object property of surface albedo but rather that in a well-articulated field, Os show an insensitivity to

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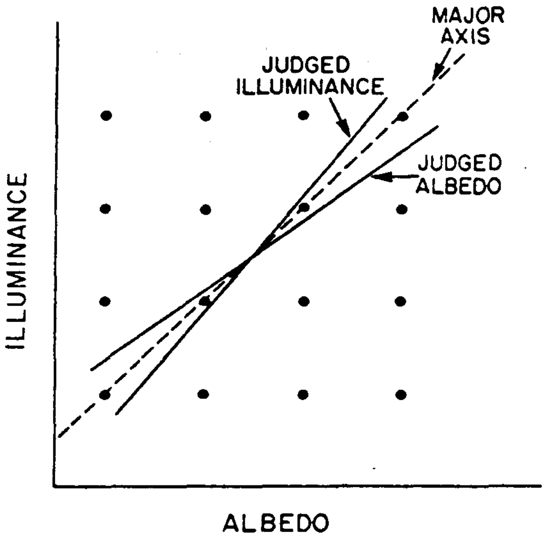

Fig. 1. Hypothetical discriminants and major axis plotted in a stimulus space. A single surface appears in isolation, preventing discrimination of albedo from illuminance. The solid lines represent the discriminants, and the points represent the orthogonal stimulus set.

illumination changes. This implies that Os do not have the ability to separate perceptually albedo and illuminance.

Methodology for demonstrating perceptual independence has taken several forms. Garner and Morton (1969) present a useful logical analysis of the problem, leading to a nonmetric, uncertainty analysis methodology. The basis for a metric analysis is presented in Hake, Faust, McIntyre, and Murray (1967) in the context of size constancy. This latter technique is more appropriate for whiteness constancy, where a physical metric for the stimuli is present.

Consider the following simple experiment. The O views a single surface in isolation. Between trials, both the albedo of the surface and the intensity of the illumination vary. On any one trial, the O responds with a category judgment of the perceived albedo. These categories range from "dark" to "light," and their number (say, four) is restricted by the E. On a second series of trials using the same stimuli, the O responds with similar category judgments of the perceived illuminance.

Figure 1 illustrates a *stimulus space*, i.e., the Euclidean space of the dimensions along which stimuli vary. Presume that four values of albedo and four values of illuminance are used in the experiment, resulting in 16 stimulus pairs plotted as points in the space. Over all trials, the stimulus series is *orthogonal*, i.e., the 16 stimuli are presented equally often. The methods of Hake et al (1967) allow computation of two *discriminants* from this experiment, one for judgments of albedo and one for judgments of illuminance. For example, the discriminant derived from albedo judgments represents the direction in the space along which perceived albedo varies maximally. In general, two stimuli that differ in the direction parallel to this discriminant will be judged to have different albedos: two stimuli that differ in a direction orthogonal to the discriminant will be judged to have identical albedos. The discriminants are plotted as lines with arbitrary intercept in Fig. 1.

The angle between the discriminants is an indication of the perceptual separation of the dimensions of stimulus variation. That is, to the extent that the discriminant derived from albedo judgments is not parallel to the discriminant derived from illuminance judgments, the dimensions show partial perceptual independence. In the experiment described above, there are no reliable cues to changes in albedo separate from changes in illumination; the perceived values are truly one-dimensional. This failure of constancy is indicated by the colinearity of the discriminants.

This notion of independence of dimensions is tied with a second concept, *grain*. A stimulus space may be grained in that the ability of the O to perceive stimulus variation in one direction may be better or worse than in another. This is the case in Fig. 1, in which judgments of albedo and illumination are highly related. Because a single surface appears in isolation, practically the same discriminant results when the O is judging either albedo or illuminance. The direction of this discriminant in the stimulus space, the *principal* or *major* axis, describes the direction of stimulus change that is most easily resolved. The existence of grain implies a limit to the perceptual independence of stimuli in that the dimensions of variation are somewhat *inseparable* (Shepard, 1964: Hyman & Well, 1968; Handel, 1967); their perceived effects may show *stimulus integrality* (Lockhead, 1966).

The stimulus situation described above is one in which a failure of constancy would be demonstrated either by the classical null-match operation or by the methods of Hake et al (1967). The stimulus situation could be changed to one that allows whiteness constancy by adding a background of constant albedo (patterned stimuli). There are now two surfaces in view, one that varies in albedo between trials and one that is constant. Given that illuminance varies between trials as well, what effect will this manipulation have on the grain in the stimulus space of Fig. 1? One suggestion comes from inferential theories of constancy. There are now two sources of information, i.e., luminance of the variable surface and luminance of the constant background. These are separable in the O's experience and thus he will be able to judge illuminance as well as albedo of the variable surface, implying that the discriminants in Fig. 1 will no longer be colinear. The discriminant for judged albedo should be parallel with the albedo axis, and the discriminant for judged illuminance parallel with the illuminance axis. In short, the Os will show whiteness constancy, and little graining will be evidenced.

Another possibility exists that receives some support from the literature. The addition of the constant surround may *not* make albedo and illuminance perceptually separate, but rather rotate the grain of the stimulus space so that it is nearly parallel with the albedo axis. If this is the case, it would imply that variation in albedo would be easily resolved, i.e., discriminants derived from albedo judgments would be nearly parallel with the albedo axis. Further, variation in illuminance would be in a direction orthogonal to the grain, making judgments of illuminance difficult. If this stimulus space is highly grained, the discriminant derived from illuminance judgments would be nearly parallel with the albedo axis. The suggestion is, then, that addition of a constant surround may make the Os insensitive to real illuminance changes. The ability of the O to show constancy, i.e., to judge real albedo changes, is produced not by a noise suppressive process applied to illuminance variation, but rather by illuminance no longer functioning as noise.

There are a number of reasons for believing that the grain in this stimulus space will be nearly parallel with the albedo axis. Several *theories* of whiteness constancy imply that perception of illuminance is not a necessary condition for constancy (Hurvich & Jameson, 1966; Cornsweet, 1970; Land & McCann, 1971). In general, these theories point to adaptive processes of the visual system (e.g., pupil diameter, general neural adaptation, lateral inhibition) and thereby question whether the visual system could respond to luminance in any absolute fashion. A number of studies have performed the important operation of analyzing *illuminance* judgments in a constancy situation and have found that the stimulus conditions producing constancy are not necessarily those producing accurate illuminance judgments (MacLeod, 1940; Beck, 1959, 1961, 1965). Together, these data and theories imply that the grain in the stimulus space will not be parallel with the illuminance axis, because that is a difficult form of stimulus variation to judge.

Other data indicate that the potent stimulus variable in this situation is variation in real albedo. For example, Wallach (1948) projected two stimuli, each of which was composed of a luminous disk in the center of a larger ring. He set the luminance of both rings and one of the disks, and asked his Os to adjust the second disk so that it looked identical in brightness with the first disk. The results were that the Os adjusted the second disk so that the ratio of disk to ring luminance was equal in both stimuli. These results are related to the grain expected in the stimulus space in Fig. 1 because varying illuminance incident on two surfaces preserves the ratio of their luminances. Presumably, they should look equally bright, that is, whiteness constancy should be shown. One implication of his results is that Os are sensitive to the orthogonal form of stimulus variation, i.e., to stimuli in which the ratio of disk to ring luminance is not equal. With the patterned stimuli, this form of variation is obtained by varying real albedo. More direct evidence, but continuing this trend, comes from a series of studies attempting to describe the stimulus conditions under which surfaces of different albedos will be seen as such (e.g., Arend, Buehler, & Lockhead, 1971; Cornsweet, 1970; Land & McCann, 1971). The general conclusion has been that Os are particularly sensitive to abrupt changes in luminance, such as that produced by two adjacent surfaces of differing albedo, and particularly insensitive to gradual luminance shifts, such as that produced by nonuniform illumination. These results can be summarized in terms of the present model by hypothesizing that with the patterned stimuli, albedo variation is the potent stimulus variable and describes the major axis of the stimulus space. Variation in illuminance runs counter to this graining and should be a difficult form of stimulus variation to judge.

METHOD

Observers

The three Os, two of which were graduate students in psychology and the third an undergraduate student, were paid for their services. All had made brightness judgments in a prior experiment for 12 45-min sessions. They were given extensive practice with feedback in the experimental conditions described below prior to the beginning of the experiment proper.

Apparatus and Stimuli

Six neutral Munsell papers were chosen for stimuli, five covering the value range from 6.0 to 7.0 in .25-value steps (nominal albedo, .301, .330, .362, .395, and .431, respectively) and used as variable papers in the experiment. The sixth, Munsell 3.5, was used as the constant surround for the patterned stimuli and had a nominal albedo of .090. For the unpatterned stimuli, each of the variable papers were mounted on cardboard and hung 18 in. from the end of a 36-in. viewing alley. A 1-in. square aperture mounted on the end of the alley provided the borders for the stimuli. The patterned stimuli were made by mounting the 3.5 Munsell paper on cardboard. The variable papers were cut in 1½-in. square pieces, and one of these was mounted in the center of each surround. A 2-in. aperture at the end of the alley provided the borders for these stimuli. The central squares subtended 1.6 deg, the same visual angle as the unpatterned stimuli, and appeared in the center of the aperture, subtending 3.2 deg. For each experimental condition, the proper stimuli were set in an eight-place holder that could be moved in a direction perpendicular to the alley, positioning any one of the papers quickly and accurately. Stimulus duration was controlled by a Hunter timer (Model 111-C) that activated a 24-V power supply for a rotating actuator (Electrolux 20100). This actuator operated a flat black shutter that occluded the aperture at the end of the viewing tunnel between stimulus presentations.

Two matched projectors (Sawyer 500 XM) with 300-W bulbs (GE CWD) were mounted on either side of the alley, 36 in. from the stimuli and at an angle of ±15 deg to a line normal to the papers. To increase the uniformity of illumination, an unpatterned milk glass was placed in each projector at the position normally occupied by a projected slide, and the projectors were focused in front of this plane. Five values of illuminance were selected to form an equal-interval log scale. The nominal values were 1.76, 1.97, 2.18, 2.42, and 2.69 fc computed from luminance measured on the 6.25 surface. These values were chosen so that changes in illumination and albedo were about equally resolvable with the unpatterned stimulus. A black cardboard slide was arranged so that light from either projector could illuminate the papers.

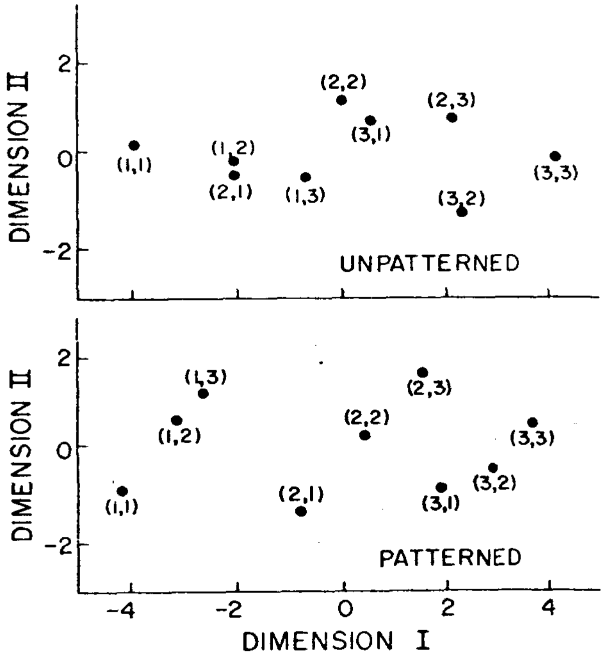

Fig. 2. Scale values from the multidimensional similarity scaling. The numbers next to each point refer to the ordinal values of albedo and illuminance, respectively, for that stimulus.

Procedure

Two classes of judgments were made on these stimuli. For the first class, category judgments, four papers were used, 6.0, 6.25, 6.5, and 6.75, and the four lower values of illuminance. The four experimental conditions in which these types of judgments were taken are defined by the combinations of the two stimulus situations, patterned or unpatterned, and by the two types of judgments, illuminance or albedo. During a single session, 176 trials were run on a single experimental condition. The first 16 were practice and not scored; a short break was taken between Trials 96 and 97. The trial series were randomized in blocks of 32, with the restrictions that two replications of each of the 16 pairs of illuminance and albedo be given and that no more than two repetitions of any one illuminance or albedo value be given in a row.

Prior to each trial, the O kept his head away from the viewing hood to prevent progressive dark adaptation. A small reading light with a 40-W incandescent bulb illuminated the gray surface of the apparatus to provide an adapting light. Each 1-sec stimulus presentation was initiated by the O after verbal announcement of the trial number by the E. The O then verbally reported his response and recorded it. Response classes were coded 1 (darkest), 2, 3, or 4 (lightest). During the 8-sec intertrial interval, the E set the disk and ring luminances for the next trial. No feedback was given.

The second class of judgments, judgments of the similarity of pairs of unpatterned or patterned stimuli, was obtained in some sessions. This is a more primitive operation than category judgments in that it requires the O to describe how different two stimuli appear, regardless of the apparent source (illuminance or albedo) of the difference. This is of particular importance whenever there is some question of the O's understanding the perceptual effects of variance in any stimulus dimension he is asked to judge. Further, they provide a description of the grain in a stimulus space. Mathematical techniques (Torgerson, 1958) allow placement of the stimuli in an n-dimensional space so that the distance between any stimulus pair reflects their judged similarity. The dimensionality, i.e., the size of n, represents the number of dimensions along which the stimuli are perceived as varying. In a highly grained space, this may be less than the number of *physical* dimensions. In addition, the separation of two stimuli should reflect the ease of discriminating between the pair. Stimulus change in some direction in a stimulus space may be discriminable but represent small perceived change.

Judgments of similarity were taken on nine stimuli, consisting of all possible combinations of three papers, Munsell 6.0, 6.5, and 7.0, and three values of illuminance, 1.76, 2.18, and 2.69 fc. During each experimental session, 80 trials were run, the first 8 being discarded as practice. The 72 possible different pairs of the nine stimuli were presented in random order.

The O initiated the stimulus sequence after a verbal announcement of the trial number by the E. One trial consisted of a 1-sec presentation of an illuminance-albedo pair followed in 2.5 sec by a 1-sec presentation of a different pair. The O then verbally reported his response and recorded it. During the 2.5-sec interstimulus interval, the E blocked the light from one projector, allowing the other to illuminate the stimuli, and moved the paper holder to center another, but not necessarily different, paper. During the 20-sec intertrial interval, the E adjusted the projectors and the paper holder for the values of the stimuli on the next trial.

An attempt was made to have the Os judge the similarities on a ratio scale. On the basis of pilot work, it was determined that the largest perceived difference with both the unpatterned and patterned stimuli was between the darkest illuminant–lowest albedo stimulus and the brightest illuminant–highest albedo stimulus. Every 20 trials, this combination was presented and named. The Os were encouraged to call that difference "10," and to judge all perceived differences in ratio relationship to it. For example, they were asked to respond "5" when the perceived difference in some pair was half of this extreme difference. However, only integers from 0 to 10 were alowed as responses.

Four sessions were devoted to each of the two types of similarity judgments, and the projector illuminating the stimulus seen first was counterbalanced over these replications. Three sessions were devoted to each of the four category-judgment conditions. These 12 experimental sessions were randomized for each O so that each condition was given n times before any one was given n + 1 times. The two similarity-judgment conditions were randomized within this series with the same restriction. After all sessions had been run for one O, the data from equivalent conditions were pooled. Over all sessions, 32 replications of each stimulus were presented for the four types of category judgments, and 8 replications of each stimulus pair were presented for the two types of similarity judgments.

RESULTS

Results from the similarity scaling are presented first. The basic data for these analyses were the judged similarity of the 72 stimulus pairs averaged across Os and sessions.[1] Torgerson's (1958) B* matrix was computed for both data sets, and an eigenvector solution to each matrix was obtained. The first two orthogonal dimensions were weighted by the square root of the variance along the dimension.[2] These are presented in Fig. 2, in which the top graph is a plot of the unpatterned stimuli, and the bottom, the patterned. Although two dimensions have been plotted, real stimulus variation is related only to the first dimension in the unpatterned situation. That is, the Os were unable to distinguish albedo from illuminance, but responded to some combination of the two. The ends of this dimension are marked by the extreme stimuli: the darkest illuminant–lowest albedo is at one end and brightest illuminant–highest albedo at the other. All stimuli are arranged in approximate order of luminance.

The scaling solution from the patterned stimuli differs from the solution for the unpatterned in two respects. First, there is a two-dimensional solution, i.e., both dimensions in Fig. 1 relate to properties of the physical stimuli. Second, most of the variance in stimulus scale values is related to albedo differences in the pairs of stimuli. The solution from the unpatterned situation suggests that when the constant surround is not present, the range of perceived variation in albedo is about the same as the range of perceived variation in illuminance. The solution from the patterned situation indicates that the stimuli were segregated into small subsets on the basis of real albedos. Variation in real illuminance produced only small but consistent changes in scale values within these groups. Consistent with these data is the suggestion that the major axis of perceived variation had shifted in the direction of the albedo dimension in the stimulus space of Fig. 1.

These results are mirrored by those obtained from category judgments. The basic data for these analyses were the distributions of the 16 albedo-illuminance stimuli in the four response classes for each O. The stimuli were scaled as log illuminance and log reflectance, and then expressed as z scores of their respective distributions. Table 1 contains the results of several analyses performed on these data according to computational formulas contained in Hake et al (1967).

The first column in Table 1 contains, as measures of accuracy of performance, the ratio of the between-response-class sum of squares (B) to the within-response-class sum of squares (W), suggested by Hake et al because of the generality of its interpretation. The square root of this measure, $(B/W)^{1/2}$, indicates how accurately the Os were able to judge the E-defined dimension of stimulus variation. These data indicate a consistent trend for greater accuracy of illuminance than albedo judgments in the unpatterned situation, implying that the major axis of stimulus variation is more highly related to the illuminance axis than the albedo axis. When the constant surround is added, this trend is reversed: there is a decrease in accuracy of illuminance judgments, and a corresponding increase in accuracy of albedo judgments. This result is consistent with the suggestion that the constant surround functioned to shift the major axis so that it was now nearly colinear with the albedo axis. Further, the marked increase in accuracy of albedo judgments with the patterned stimuli is an index of the whiteness constancy possible with these stimuli.

Discriminant analyses on these same data allow a clearer description of this constancy trend. One assumption necessary for these analyses to be meaningfully related to performance is that on each trial the O judged a single effective stimulus (S_i) that was

Table 1
Analyses of Category Judgments

	Stimulus	Judgment	$(B/W)^{1/2}$	$\lambda_1^{1/2}$	$\frac{\lambda_1}{\lambda_1+\lambda_2}$
O 1	Unpatterned	Ill	.677	.992	.988
	Unpatterned	Alb	.512	1.010	.991
	Patterned	Ill	.351	.733	.993
	Patterned	Alb	.986	1.179	.994
O 2	Unpatterned	Ill	.779	1.277	.996
	Unpatterned	Alb	.561	1.162	.999
	Patterned	Ill	.257	.952	.999
	Patterned	Alb	1.175	1.544	.995
O 3	Unpatterned	Ill	.731	1.025	1.000
	Unpatterned	Alb	.356	.852	.997
	Patterned	Ill	.216	1.145	.999
	Patterned	Alb	1.342	1.524	.994
O 1*	Patterned	Ill	.235	1.034	.991
O 2*	Patterned	Ill	.437	1.353	.997
O 3*	Patterned	Ill	.409	1.183	.986

**These results are from data collected as a separate experiment.*

some linear combination of the albedo and illuminance present on that trial. Further, the O assigned S_i to response classes so as to maximize the ratio of between- to within-response-class sum of squares. The square root of this ratio, $\lambda_1^{1/2}$, is a measure of consistency of responding, indicating how coherently the Os were able to respond to stimulus variation. Table 1 contains these measures, which indicate that the Os were able to judge albedo and illuminance with about equal consistency in the unpatterned situation. Mirroring the constancy trend, all Os were more consistent attempting to judge albedo with the patterned stimuli.

A second solution for λ is possible (λ_2) that reflects the amount of nonlinear use of response classes. A test of the adequacy of the linear assumption is the proportion of the total between-response-class variance accounted for by a single linear combination and given by $\lambda_1/(\lambda_1 + \lambda_2)$. These measures, presented in Table 1, are uniformly high, demonstrating the linear use of the response classes in this situation.

The values of the linear combination that maximizes λ_1 are the discriminants referred to earlier. These are plotted for each O as solid lines with arbitrary intercept in the stimulus spaces of Figs. 3-5. For the present discussion, ignore the dashed lines. Also included in these figures are the response class centroids, i.e., the mean albedo and the mean illuminance assigned to each response class. The upper graph in each figure was derived from the judgments of the unpatterned stimuli. The colinearity of the discriminants derived from albedo and illuminance judgments reinforces the evidence from the similarity scaling data. None of the Os were able to discriminate albedo from illuminance but responded to a similar combination of the two when attempting to judge either.

The bottom plots in Figs. 3-5 were derived from judgments of the patterned stimuli. Partial constancy

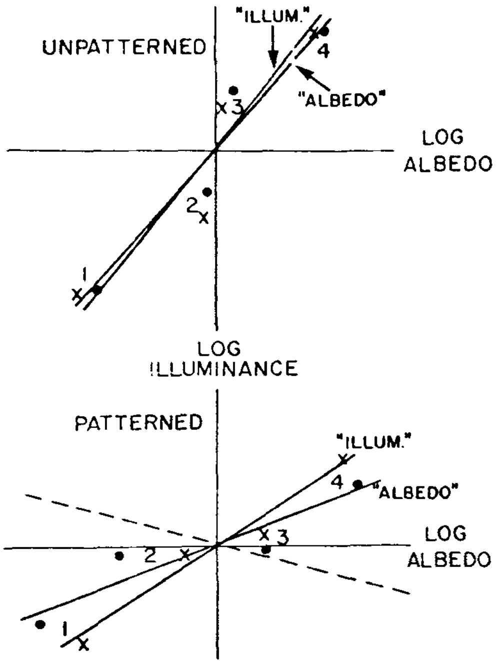

Fig. 3. Discriminants computed for O 1. The points and crosses are the response class centroids from albedo and illuminance judgments, respectively. The numbers next to each refer to the coded responses (1 = darkest; 4 = lightest). The dashed line in the bottom plot is from a separate experiment in which judgments of illuminance were given with an instructional variable added.

was present for all Os and is shown by the position of the discriminant derived from albedo judgments. With the patterned stimuli, these are now more nearly colinear with the albedo axis, although there is still some contamination from the illuminant. There is also a consistent trend in judgments of the illumination with the patterned stimuli. All Os accepted changes in albedo as changes in illuminance. The discriminants are more nearly colinear with the albedo axis than with the illumination axis. There is an individual difference, however. For O 1 (Fig. 3), there is little difference in his two discriminants derived from the patterned situation. Whether he was asked to judge albedo or illuminance, he responded with approximately the same linear combination of real illuminance and albedo. For Os 2 and 3, there is some discrimination between these two. That is, the discriminants are not colinear.

This is a pronounced individual difference and worthy of further study. None of the Os were able to judge real illuminance variation in the patterned situation with much accuracy. The $(B/W)^{1/2}$ measures of centroid separation on the illuminance axis (Table 1) are consistently low compared with the same measures of separation on the albedo axis. Thus, the two patterns of results for illuminance judgments are equivalent in that neither allows accurate judgment of illuminance.

The difference in the two modes was in the relationship of judged illuminance and the value of *albedo* present on each trial. For O 1, there was a positive correlation between perceived brightness of the illuminant and the real albedo value; for Os 2 and 3,

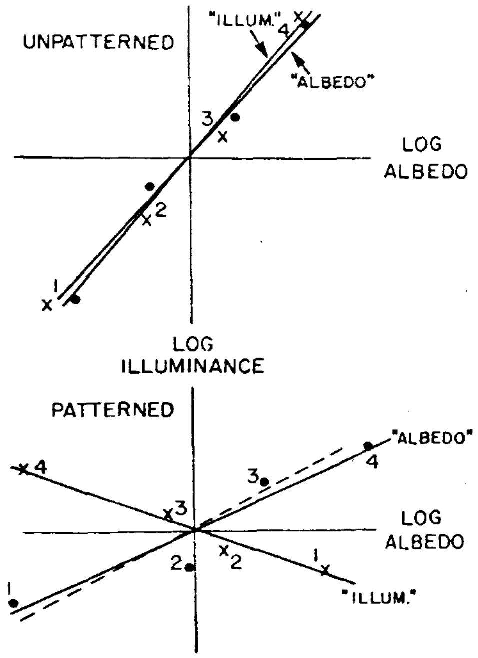

Fig. 4. Discriminants and centroids for O 2.

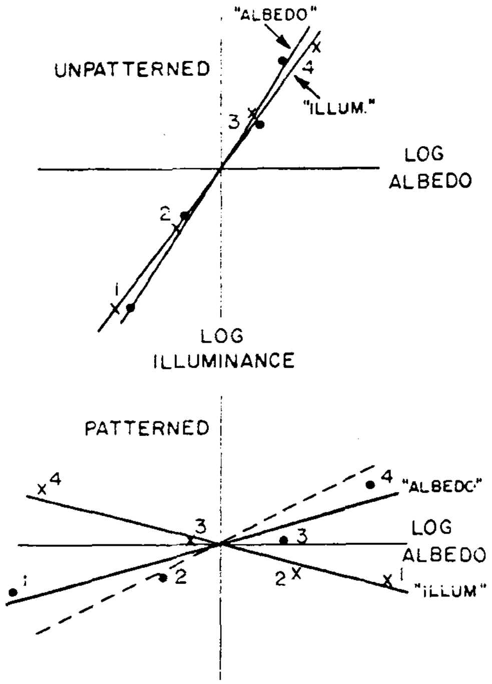

Fig. 5. Discriminants and centroids for O 3.

perceived brightness of the illuminant was negatively related to real albedo. Verbal reports taken from all of the Os revealed a possible basis for this difference. The first O reported taking information about illumination from the central square. When it appeared brighter, he responded with a value reflecting higher perceived illuminance. The other two Os reported taking information about illumination from the surround. This was physically constant in reflectance but varied in luminance as a simple function of illuminance. However, it is likely that a simultaneous contrast effect was present, i.e., the surround looked darker when a paper of higher albedo was present. This would describe the obtained negative correlation between perceived illuminance and real albedo.

This analysis indicates that there was not a basic individual difference in perception present in the pattern of results, but rather that, even with the simple stimuli presented, the Os have options. This hypothesis was tested by a short experiment that was run after all data in the main experiment had been collected. Further judgments of illuminance were taken using the patterned stimulus. The Os were encouraged to use options different from those they had used in the main experiment. The first O was told to accept apparent changes in the brightness of the surround as changes in illuminance; the other two Os were told to accept changes in the central square as changes in illuminance. The stimuli and Os used were the same as in the main experiment. Two sessions of 160 experimental trials were run for each O. Over both sessions, each of the 16 stimuli were presented 20 times.

The discriminants derived from these judgments are plotted as dashed lines in the bottom graphs of Figs. 3-5, and indicate that the Os did have options. O 1 was able to produce the same two-dimensional plot of discriminants that Os 2 and 3 gave in the main experiment; he produced a *negative* correlation of perceived illuminance and the real albedo present. The other two Os produced results similar to those O 2 gave in the main experiment. This is less surprising in that these Os had already demonstrated ability to align a discriminant in that direction when they attempted to judge albedo. However, both produced discriminants for illuminance judgments that were slightly more parallel with the illuminance dimension, suggesting that they were attempting to judge illuminance. The $\lambda_1^{1/2}$ and $(B/W)^{1/2}$ measures reflected on the illuminance axis, included at the bottom of Table 1 are about equal, regardless of whether a negative or positive correlation with albedo is produced. Either option results in centroid separation related mainly to real albedo variation.

Thus, in general, the predictions concerning the grain of the space have been verified. Addition of the constant surround changed the major axis of perceived variation to make it more nearly colinear with the albedo axis. Two hypotheses can be advanced for this effect that do not depend upon noise suppression through perception of the illumination. (1) The addition of the constant surround produced an insensitivity to illumination changes. (2) The grain of the space was produced by the presence of a patterned stimulus that *varies* in albedo.

Table 2
Accuracy of Judging Illuminance When Albedo is Constant

	Stimuli	
	Unpatterned	Patterned
O 1	.567	.409
O 2	1.371	1.175
O 3	.679	.581

A short experiment tested the difference in these two suppositions. If there was an insensitivity to the illuminant produced by addition of the constant surround, then even when the central square is constant, illuminance judgments should be less accurate than with the unpatterned stimulus. However, if the obtained grain was caused by variation in albedo, then a constant central square should produce equal accuracy with the patterned and unpatterned stimuli. The three Os were given two sessions in which only illuminance varied. The Munsell 6.5 paper was constant for both the patterned and unpatterned stimuli. These two conditions were presented in two blocks of 80 trials on each session, with order counterbalanced over the two sessions.

Table 2 contains the $(B/W)^{1/2}$ measures from these data. There was a small but consistent trend for accuracy to be less with the patterned stimuli. Thus, although there was a slight insensitivity to illuminance changes produced by addition of a surround, this was probably not large enough to produce the large change in grain evidenced in the results of the main experiment. Rather, variation in albedo dominated the stimulus space, producing an insensitivity to the orthogonal illuminance variation.

DISCUSSION

Addition of a constant surround appears to have the effect of rotating the grain of the stimulus space to run more nearly colinear with the albedo dimension, resulting in a constancy trend. Judgments of albedo were more nearly colinear with the albedo axis, and accuracy of assigning real albedo to response classes increased considerably. This partial constancy was *not* accompanied by increased accuracy of illumination judgments, but rather, perceived variation in illuminance was related mainly to real albedo variation. The Os did have options in this regard, resulting in a positive or negative relationship with real albedo. However, the options were equivalent in the obtained accuracy of illuminance judgments.

Both the results of the similarity scaling and the discriminant analyses with the patterned stimuli indicate that the perceived space was two-dimensional, although the axis for perceived illuminance was very short. No O was able to align illuminance judgments in this direction. Thus, the data are also consistent with the hypothesis that the Os could *not* separate changes in albedo from changes in illuminance. Rather, they could only judge some inseparable combination of the two. The option present resulted in the apparent two-dimensionality in both the similarity and category judgments. This allowed the O to change the *sign* of the linear combination; whether he judges illuminance or albedo, the values of the weights remain the same. For example, the direction of the discriminant derived from illuminance judgments in Fig. 5 is [−.9612 .2757], and that derived from albedo judgments is [.9580 .2868]. A similar trend holds for the other two Os. Thus, the suggestion is that the stimulus space for the patterned situation is highly grained, but in two directions. The O can resolve stimulus variation in these directions but he cannot vary much from either of them.

A second way to approach this same conclusion is by noting that the difference between perceived albedo and illuminance in the patterned situation was in the relationship of judgments with real albedo variation. There were two aspects of albedo variation, having inverse relationship, and depending upon whether information from the center or the surround was used. Thus, the partial separation of the discriminants in the bottom parts of Figs. 3-5 was produced not by partial separability of illuminance and albedo, but rather by partial separability of the two aspects of albedo variation.

Given this interpretation, a description of the constancy shown in the patterned condition need *not* include statements about noise suppression. The Os were practically insensitive to illuminance variation, the "noise" in this situation. By analogy with other communication systems, we generally do not suggest that a receiver suppresses noise when that receiver is not sensitive to the noise. For example, communication engineers generally do not include electromagnetic radiation having wavelengths on the order of 550 mμ (visible light) in calculating the amount of noise present for an AM radio. The radio need not suppress this kind of signal perturbation because it is insensitive to this wavelength of "noise."

These data and the underlying model question the traditional explanation for the Gelb effect (Gelb, 1929). This phenomenon can be demonstrated if, in a room illuminated by a dim ceiling light, a black surface receives intense light from a concealed projector. The light from the projector falls only on this surface, no additional light being cast on the background. Under these conditions, the surface appears white, and changes in the illuminance of the light falling on it causes perceived change in its lightness. These conditions are similar to the unpatterned conditions in the present study. The Gelb effect is completed by inserting a white paper so that it intercepts the projector beam, resulting in veridical perception of the black surface. Further, changes in illuminance from the projector no longer cause apparent changes in surface lightness. This last stimulus situation is similar to the patterned condition in the present study. The traditional explanation for this effect is inferential in tenor, and has emphasized that addition of the white surface to the special illumination allows detection of the object color as separate from the illumination (e.g., Forgus, 1966). The present results imply that addition of the white surface makes the O insensitive to the special illumination, and particularly sensitive to the albedo differences in the white and black surfaces.

Returning to the more general definition of constancy suggested by Hake (1970), this experiment is probably not concerned with constancy at all. The dimensions of stimulus variation were not separable in the Os' experience; there is little indication that illuminance functioned as noise to be suppressed in this task. Thus, rather than an investigation of a noise-suppressive process, this experiment was concerned, in part, with a stimulus situation that produced a blindness to one form of stimulus variation.

There is some indication in the data that even this expanded definition of constancy is too simple. The final experiment, in which the Os judged illuminance variation without corresponding albedo variation, demonstrated that with the patterned stimuli the insensitivity to illuminance changes found in the main experiment was due, in the main, to albedo variation. That is, albedo variation dominated the stimulus space and produced the shift in grain. This is a *dynamic* aspect of perception in that the Os showed no constant ability to perceive illuminance change, but rather were driven by aspects of stimulus variation. The implication is that questions about the perceptual separability of two dimensions of stimulus variation may be too simple. Perceived separability depends, in part, on the amount of physical variation in multidimensional stimuli (Hake, 1970).

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NOTES

1. The scaling solutions reported were first computed for each O. Little individual difference was present so that, for purposes of brevity, only the average results are described.

2. The proportion of the trace in the B* matrix that is retained in these dimensions is not meaningful because of the presence of negative eigenroots.

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